AN ELECTRIC CONVERTER

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WM. I. BOOK

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PRESENTED TO THE FACULTY OF PHILOSOPHY OF THE UNIVERSITY OF PENNSYLVANIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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AN ELECTRIC CONVERTER.

BY WM. I. BOOK.

THIS paper describes a new method of producing electric oscillations of high frequency from a direct-current source. The apparatus is, therefore, called an electric converter.

In this method of producing electric oscillations the primary and secondary oscillating circuits are arranged in the same manner as they are for producing electric oscillations with the Duddell arc, and with the Poulsen arc. But the converter differs much from all other methods previously used to produce continuous electric oscillations.

DESCRIPTION OF APPARATUS.

The converter consists of a powerful electro-magnet with heavy tubular pole pieces, *a*, about 7.6 cm. in diameter. (See Fig. 1.) The walls of these pole pieces are reamed out, or tapered, at the end to a thickness of about 0.45 cm. Fitted on the end of each of these pole pieces is a fiber ring, *b*, about 10 cm. in outer diameter. To this fiber insulation is attached a copper (cathode) ring, *r*, about 5.6 cm. in inner diameter (to be described below). One of the tubular pole pieces is filled with a plug of fiber, *c*. A brass rod, *d*, neatly fits into a longitudinal hole through the center of this fiber plug. This rod is thus insulated from the pole pieces. There is fastened to the end of this rod by means of a machine screw a zinc or carbon (anode) disc, *e*, about 5.4 cm. in diameter. The faces of the fiber rings, mentioned above, project slightly beyond the ends of the pole pieces, making sockets into which are fitted discs of mica, *g*, over the ends of the pole pieces. These mica discs with the fiber rings insulate both the anode disc and the cathode ring from the pole pieces.

If a difference of potential of approximately 500 volts is impressed across the gap between the anode disc and the cathode ring, under the proper conditions, a spark or discharge will take place across the gap. Now if there is a current in the coil of the electro-magnet there is a powerful magnetic field between the poles of the magnet; the lines of force of the magnetic field passing chiefly through the gap between the anode disc and the cathode ring. The direction of the spark, therefore, is perpendicular to this magnetic field, and, in accordance with the funda-

mental principle which underlies the action of an electric motor, there is a force action on it perpendicular to both the magnetic field and the direction of the spark discharge. This causes the discharge to move around and around the circular gap between the anode disc and the cathode ring. But either the anode disc or the cathode ring must have a rough surface in order to obtain the conditions necessary to produce oscillations in an oscillatory circuit shunted about the spark-gap. It

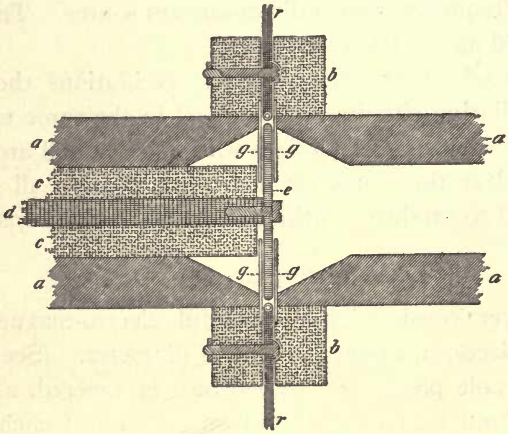

Fig. 1.

was found best to put a regularly roughened surface on the cathode ring. Different methods were tried for producing this regularly roughened surface. The simplest and most successful method tried was carefully to wind a soft copper wire of, say, No. 16 gauge on a ring made of No. 10 or No. 11 gauge wire. This wire-wound ring, *r*, was then soldered into a circular hole cut in a sheet of copper, this sheet of copper serving not only as a conductor to which the line from the negative brush of the dynamo is attached, but also as a heat radiator for the cathode ring, thus keeping it reasonably cool.

Connections of Apparatus.

In Fig. 2, there is shown a general diagram of the connections of the apparatus. The source of difference of potential used, (E), was two ¼ horse-power 500 volt D.C. dynamos joined in parallel. R_0 is a variable resistance consisting of a bank of carbon filament lamps in series with a slide-wire contact resistance capable of varying the main current from about 1/10 of an ampere to about 1 ampere. I_0 is a direct current milli-ammeter with which to measure the current in the main circuit. L_0 is a

choke coil. The high tension side of an ordinary electric light transformer was used for the choke-coil. *G* is the gap between the anode disc and the cathode ring. C_1 is a variable capacity in oil. C_2 is a similar capacity in the secondary oscillating circuit. L_1 is the primary of a closely wound induction coil. L_2 is the secondary of this coil. I_1 is a hot wire ammeter with which to measure the current in the primary oscillating circuit. R_2 is a variable resistance consisting of a bank of carbon filament lamps.

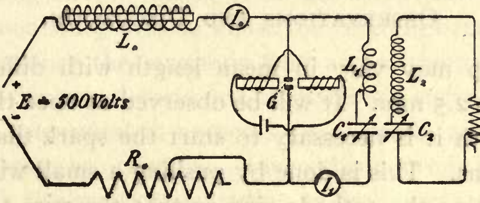

Fig. 2.

THEORY AND PRINCIPLES OF THE ACTION OF THE SPARK-GAP.

When the apparatus is connected as shown in the diagram, Fig. 2, and when the proper conditions are produced for the spark discharge to take place, the spark will pass around and around in the gap between the inside disc and the outside regularly roughened or notched ring. Because of the notches or grooves in the outside ring the sparking distance alternates rapidly from a given minimum to a given maximum as the discharge passes around the gap; and, therefore, the resistance of the gap likewise varies with this varying length. The function of the choke coil in the main circuit now appears. It serves to maintain a nearly constant supply of energy through the gap and the primary oscillating circuit shunted around the gap. When the spark is passing between the inside disc and a *ridge* on the outside ring the resistance across the gap has a minimum value, but when the spark is passing between the disc and a *groove* in the outside ring the resistance of the gap is a maximum. There will, therefore, be a rapdily alternating *flow* and *ebb* of energy into the primary circuit,—at each high resistance in the gap a *flow*, at each low resistance in the gap an *ebb*. Since the primary oscillating circuit has a natural frequency of its own, it would seem that the oscillations in this primary circuit for a given set of conditions will have an increased amplitude,—and, therefore, a greater amount of energy will be in the primary circuit,—when the natural frequency of the primary oscillating circuit is an integral multiple of the frequency of the flow and ebb of energy into this circuit due to the alternating higher and lower resistances in the spark gap.

A number of variables however enter into the investigation of these circuits and the complete determination of their inter-relation is not as simple a problem as at first it seems to be. The D.C. voltage impressed across the gap, the amount of current in the main circuit, the average length of the spark gap, the number of ridges and grooves in a given length of arc of the spark gap circumference, the intensity of the magnetic field through the gap; these are some of the quantities to be investigated.

Observations and Discussion.

The spark-gap may vary in mean length with different conditions from 0.2 mm. to 2.5 mm. It will be observed at once that with a spark gap of this length it is necessary to start the spark discharge by some mechanical means. This is done by pushing a small wire into a groove in the fiber next to the cathode ring so that the wire touches both the inside disc and the outside ring. This closes the main circuit. The wire is immediately withdrawn, thus starting the spark discharge.

The curves of Fig. 3 show the result of using different lengths of spark gap. The curve marked "Zn_i" shows the variation of current in the

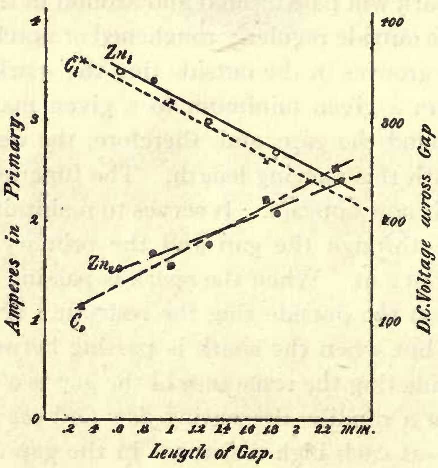

Fig. 3.

Variation of current in primary with change of spark-gap length. Variation of voltage across gap with change of spark-gap length. Field = 4,500 gauss, $I_0 = 0.65$ amp., $C_1 = 3.4 \times 10^{-2}$ M.F.

primary oscillating circuit with a change in the length of the gap when zinc was used for the anode disc. The curve marked "C_i" shows the same thing for carbon as the anode disc. On the same chart are shown

two curves which illustrate the variation of D.C. voltage across the gap with a change of spark gap length. These curves are marked "Zn_v" and "C_v." For best results the spark gap should be from 0.4 mm. to 1.5 mm. in length. These curves seem to indicate that zinc or carbon may be used for the anode disc with approximately the same results. Brass and aluminium were tried with practically the same success.

The study of the effect of a varying field upon the current in the primary oscillating circuit follows. To get the relation between these quantities it is necessary first to know the relation between the current in the coil to produce the magnetic field across the gap, and the field itself. This relation was determined by plotting a curve with the current in the field coil, measured in amperes, as abscissas and with the field, measured in gausses, as ordinates. From this curve it was easy to note the field through the gap corresponding to any current in the field coil. The method used to determine the field strength was the method of the bismuth spiral; the pole pieces being kept at the same distance from each other as they are when the anode and cathode parts are between them, *i. e.*, at a distance of approximately 0.7 cm.

If, now, the spark discharge be started and all the variable quantities in both the main circuit and the oscillating circuits be kept constant, but the field be increased gradually, the current in the primary oscillating circuit will also increase. It does not, however, increase as a straight

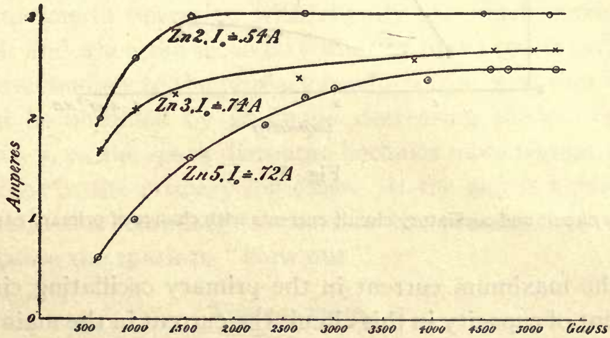

Fig. 4.

Current curves with change of field across gap. $C_1 = 3.4 \times 10^{-3}$ M.F., $V_1 = 125$ to 230 volts, depending upon length of gap. $\lambda_1 = 330$ m.

line function, but rises to a maximum above which an increase of field will not further augment it. If the field is increased considerably beyond the value which, for a given set of conditions, will give the maxi-

mum current in the primary oscillating circuit the spark discharge sputters or becomes noisy and the energy in the oscillating circuit is decreased rather than increased. In Fig. 4 are shown three characteristic curves illustrating the above mentioned result. The readings for the curve marked "*Zn* 2" were obtained when a spark gap of 0.85 mm. was used. The spark gap for the curve "*ZN* 3" was 1.3 mm. long, and that for the curve marked "*Zn* 5" was 2.3 mm. in length. The explanations of this result that have suggested themselves to the writer are not entirely satisfactory to him and are reserved for further verification.

The curve of Fig. 5 marked I_1 shows the increase of current in the primary oscillating circuit with a gradual increase of the capacity in that circuit. The curve marked I_0 shows the amount of current in the supply circuit corresponding to these different amounts of capacity and current in the primary oscillating circuit. The readings for the curves were taken with the magnetic field across the gap maintained at about 4,500 gausses.

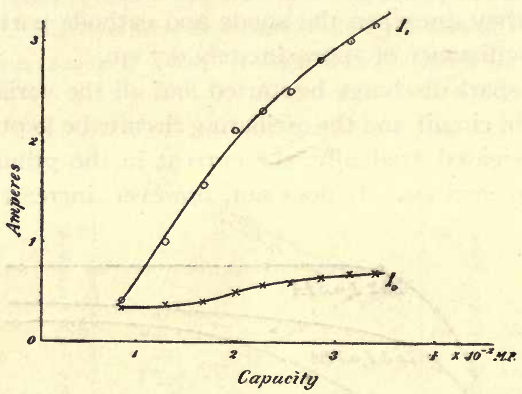

Fig. 5.

Supply circuit and oscillatory circuit currents with change of primary capacity.

To get the maximum current in the primary oscillating circuit for a given amount of capacity in this circuit the current in the main, or supply circuit must not be too large. When there is too much current in the main circuit the spark discharge sputters and is irregular, and thus little energy gets into the oscillating circuits. But when this condition is present, if the supply current is gradually decreased the gap runs more and more smoothly, and the current in the primary oscillating circuit gradually increases. If the supply current is still gradually decreased by means of the variable resistance in the main circuit the current in the oscillating circuit continues to increase until it comes always to a maxi-

mum value for the given capacity in the circuit. If the supply current is decreased yet a trifle the spark suddenly stops—"blows out." This is a very characteristic phenomenon of the converter. It seems to indicate that as the energy in the oscillating circuit becomes greater and greater a condition is reached where the back E.M.F. impressed across the gap due to the oscillations in this circuit is sufficient to reduce the D.C. voltage across the gap to too low a value to maintain the spark discharge.

The number of notches per unit length of arc of the spark gap circumference is an important factor in determining the amount of energy that is transformed in the oscillating circuits. A very large number, say 25 per centimeter of arc, is of no advantage, but rather of a disadvantage. If the number be too large the spark discharge, or arc, spreads over several of them, and thus a regular and considerable rise and fall of the spark gap resistance is not obtained. On the other hand if the number of notches be too few then the number of pulses per unit of time is not sufficient, with a low field across the gap, to maintain the oscillations in the primary circuit. However, with only 54 notches in the entire circumference of the gap the current in the primary increases very rapidly as the magnetic field across the gap is increased. The best results were obtained with a cathode ring made with about 10 notches per centimeter of arc.

Among the observations made in connection with the secondary circuit one notable fact was observed. It was frequently noticed that when the gap was in operation with slightly too much current in the supply circuit and when the secondary was not tuned to the primary, the tuning of the secondary to the primary produced the condition in the gap which would be obtained by gradually decreasing the current in the supply circuit; *i. e.*, the spark discharge becomes more regular and quiet and the current in the primary increases. If the gap is already acting smoothly before the secondary is tuned to the primary an attempt to tune it will cause the spark to "blow out."

Application.

A very interesting application of this new converter occurs in wave-telegraphy. The writer has at different times successfully signalled by means of it to a private wireless station three city blocks distant. These signals were very distinctly heard at stations at a distance of from three to five miles from the Randal Morgan Laboratory of Physics where this research was pursued.

There are several ways to produce the signals with this apparatus. One method is to join in series with the secondary circuit (which is the

antenna circuit here) a suitable resistance of, say, carbon filament lamps and shunt this resistance with the signaling key. Upon pressing the key to produce a signal the resistance is shunted and the energy in the secondary is radiated through the antenna instead of being used to heat the resistance. Another method is to join in parallel with the antenna circuit a secondary which can be tuned to the primary. These two circuits have placed in them a double-action key. When this secondary circuit is closed it diverts the energy from the antenna circuit. When the key is pressed to produce a signal the tuned secondary circuit is broken. The energy then "flows" into the antenna circuit and is radiated by it.

It is the confident belief of the writer that this method of producing continuous high frequency oscillations will succeed not only in wireless telegraphy but also in wave-telephony.

Summary.

1. A result of this research is that an electric converter to produce continuous electric oscillations of high frequency has been constructed which applies the fundamental principle of the electric motor. A gas serves as the conductor. A radial spark discharge takes place through air at right angles to an intense magnetic field; and in accordance with the electro-dynamical principle involved there is a force action on the spark perpendicular both to the direction of the magnetic field and to the direction of the spark discharge, causing the spark to move rapidly around in a circular gap.

2. An advantage of this converter consists in the fact that the spark discharge takes place in air instead of in some other gas such as hydrogen.

3. To produce the electric oscillations in the oscillatory circuit the circular spark gap should be regularly notched with about 10 notches per centimeter of arc.

4. The length of the spark gap may be from 0.4 mm. to 2.5 mm.

5. An increase of the magnetic field across the gap increases the energy in the oscillatory circuit but not in constant ratio with the increasing field.

6. By increasing the capacity in the primary oscillatory circuit the oscillating current is rapidly augmented, while the increase in the supply current to make possible such increase of capacity is small.

7. Too large a supply current decreases the energy of the oscillatory circuit. For a given set of conditions if the supply current be gradually decreased the oscillating current increases until a condition is reached where further decrease of supply current causes the spark to suddenly stop.

8. This type of electric converter is well adapted to use in wave-telegraphy.

In conclusion I wish to thank Professor A. W. Goodspeed, director of the Randal Morgan Laboratory of Physics, for placing at my disposal the facilities of the laboratory which made possible this investigation. I also wish to acknowledge my indebtedness to Dr. R. H. Hough for much valuable assistance, and for suggesting to me the fundamental idea from which this research developed.

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